

# First Ultraviolet Spectrum of a Brown Dwarf: Evidence for H<sub>2</sub> Fluorescence and Accretion<sup>1</sup>

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## ABSTRACT

We analyze an HST/STIS ultraviolet spectrum of the young brown dwarf 2MASSW J1207334-393254, a member of the ten million-year old TW Hya Association that has a planetary-mass companion. We detect and identify numerous emission lines. CIV and other ions are seen that arise in hot gas. We identify a series of lines with Lyman-pumped H<sub>2</sub> molecular lines, indicating that cool gas is also present. Overall, this substellar object shows many of the same characteristics as classical T Tauri stars. We interpret our results as direct evidence of accretion from a circumstellar gas disk, consistent with previous claims. The lack of SiIV emission from the accreting gas indicates that silicon has been depleted into grains.

*Subject headings:* stars: formation — stars: low-mass, brown dwarfs — circumstellar matter — planetary systems: protoplanetary disks — stars: individual (2MASSW J1207334-393254)

## 1. Introduction

It has long been speculated that the star formation process results in both stars above and brown dwarfs below the hydrogen-burning limit. With the discovery of many brown dwarfs in star-forming regions, their formation and early evolution can now be observed. Infrared excesses indicate that many brown dwarfs are surrounded by dusty disks (Jayawardhana et al. 2003; Liu et al. 2003; Mohanty et al. 2004). In at least one case, a brown dwarf of  $0.015M_{\odot}$ , just above the deuterium-burning limit, has a disk (Luhman et al. 2005). Twenty-seven out of seventy-four young ( $< 3$  Myr) very-low-mass stars and brown dwarfs also have

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optical emission lines including broad  $H\alpha$ , which are interpreted as due to accretion (Mohanty et al. 2005). The accreting brown dwarfs are thus considered analogs of substellar classical T Tauri stars. The star forming region brown dwarfs are too distant to resolve close binaries, but Hubble Space Telescope studies of nearby older field brown dwarfs indicate that 20% of them are binaries with separations  $\lesssim 10$  A.U. (Gizis et al. 2003). In summary, there is ample evidence that in many respects the formation of brown dwarfs is similar to that of stars.

The closest known brown dwarf with a disk is 2MASSW J1207334-393254<sup>2</sup>. Gizis (2002) discovered this  $\sim 0.03M_{\odot}$  brown dwarf in a search for substellar members of the  $\sim 10$  Myr old TW Hya Association (TWA) and noted its strong  $H\alpha$  emission. Mohanty et al. (2003) found that the emission is variable and very broad, and argued that it is due to accretion. Gizis & Bharat (2004) set an upper limit to the presence of X-rays, and argued that this showed that no more than 10% of the  $H\alpha$  emission is chromospheric, thus supporting the accretion origin of the  $H\alpha$  emission. Sterzik et al. (2004) detected an infrared excess at 8.7 and 10.4 microns and argued for the presence of a disk. Jayawardhana et al. (2003) earlier showed there is no L' (3.8 micron) excess, indicating the disk may have a growing inner hole as in the TWA members TW Hya and Hen 3-600A (Jayawardhana et al. 1999a,b). It is worth noting that the system's youth is confirmed by its low surface gravity (Gizis 2002) and lithium (Mohanty et al. 2003), and TWA Membership is confirmed by both radial velocity (Mohanty et al. 2003) and proper motion (Gizis 2002, Scholz et al. 2005). TW Hya itself is at a distance of 55 parsecs (Perryman et al. 1997), but it has been argued that 2M1207 is further away, perhaps at 70 parsecs (Sterzik et al. 2004). As if this system were not interesting enough, Chauvin et al. (2004) detected a candidate giant planet companion at a separation of 0.78 arcseconds or 55 A.U.. The L dwarf nature of the companion has been confirmed by (Schneider et al. 2005). Proper motion confirmation is underway.

In this paper, we present an ultraviolet spectrum of 2M1207. Unlike objects in dusty star-forming regions, the TWA is relatively free of extinction, making 2M1207 an especially favorable target for ultraviolet spectroscopy.

## 2. Observations and Data Reduction

We observed 2M1207 on 24-25 July 2004 using Hubble Space Telescope and the Space Telescope Imaging Spectrograph (STIS) in spectroscopic mode. The grating was G140L with the FUV MAMA detectors using the 0.2 arcsecond slit. This setup gives coverage from

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<sup>2</sup>This source appears as 2MASS J12073346-3932539 in the final 2MASS release.

1100 Å to 1700 Å. Three exposures of 2150 seconds (starting at UT 23:24:43), 2900 seconds (UT 00:46:34) and 2900 seconds (UT 02:22:31) were obtained. We used the flux-calibrated two-dimensional images as created by the standard pipeline. No continuum is detected in the spectra, but numerous spectral lines are strongly detected. We traced these using standard IRAF tasks and extracted the spectra. No significant differences were seen in the spectra extracted from the three individual images (specifically, the CIV fluxes agree to within 8% in the three exposures); for the remainder of this paper, we use the spectrum extracted from an image created by averaging the three individual exposures. This spectrum is shown in Figure 1 and the measured line fluxes are listed in Table 1. To check on our procedures, we used the same procedures on the three field late-M dwarfs (VB8, VB10 and LHS 2065) observed with the same setup by Hawley et al. (2003), and found the resulting spectra were consistent with the published ones.

### 3. Analysis

Superficially, the ultraviolet spectrum strongly resembles IUE spectra of classical T Tauri stars (Valenti et al. 2000) while differing in many respects from the field late-M dwarfs. Most strikingly, numerous H<sub>2</sub> fluorescence lines are present. Herczeg et al. (2002) present line identifications for the H<sub>2</sub> lines observed in high-resolution STIS observations of TW Hya. All of our detected features match lines pumped by Ly  $\alpha$  1215Å and 1216Å photons. We do indeed detect strong Ly $\alpha$  directly in our spectrum, but its strength must be affected by interstellar absorption and geocoronal contamination. the lack of spatial extent of the emission lines indicates that the emission is from the inner  $\sim 0.2$  arcseconds (14 A.U.).

In addition to the molecular H<sub>2</sub> emission, we detect ions that must arise from very hot gas: CIV, CII, CIII, HeII, NV, and OI. All are present in both classical T Tauri stars and field M dwarfs. However, the emission lines differ significantly from the field dwarfs. In 2M1207, the two components of the CIV double are nearly equal strength (note that the apparently stronger blue component is blended with an H<sub>2</sub> line), whereas in the field dwarfs the blue component is twice as strong. This indicates 2M1207’s CIV emission is optically thick, while the field dwarf’s transition region emission is optically thin. We fail to detect SiIV, which would be easily detectable if in the same ratio as the field dwarfs, and which should arise in similar temperatures as the CIV. In classical T Tauri stars, this Si feature is also sometimes much weaker than expected (Valenti et al. 2000).

We interpret these observations as showing that 2M1207 is actively accreting from a circumstellar gas disk, following the scenarios already worked out for classical T Tauri stars (Herczeg et al. 2004)[and references therein] and as advocated by Mohanty et al. (2003) for

this source. This circumstellar gas is, for the first time in a brown dwarf, detected directly in the form of the  $H_2$  emission lines. The accretion columns have already been described by the observations of broad  $H\alpha$  emission Mohanty et al. (2003). Near the surface, this gas is (shock) heated to high temperatures ( $T \approx 10^5 K$ ). These hotspots are responsible for the CIV emission. The lack of Si emission in the hotspots is due to its depletion into dust grains in the circumstellar disk. Indeed, the dusty disk with silicate emission has been detected in the mid-infrared (Sterzik et al. 2004). The lack of detectable X-ray coronal emission confirms that chromospheric and transition region emission is relatively weak in 2M1207 compared to the emission from mechanisms described above (Gizis & Bharat 2004). Accretion is evidently variable within a night as well as on long timescales given the observed variability of  $H\alpha$  (Mohanty et al. 2003; Gizis & Bharat 2004), complicating any effort to compare non-simultaneous datasets. Overall, 2M1207 seems to be very similar to TW Hya itself. Three other TWA stars, Hen 3-600A, TWA 14 and TWA 5A (Muzerolle et al. 2001; Mohanty et al. 2003), also appeared to accrete.

These observations are particularly interesting given that 2M1207 has a giant planetary mass companion candidate (Chauvin et al. 2004; Schneider et al. 2005). Weinberger et al. (2002) argue that TW Hya originally had an unusually large circumstellar disk of  $\sim 25\%$  of the primary mass. The long accretion lifetime and observed similarity of 2M1207 raises the possibility that perhaps 2M1207 also had an unusually large disk. The candidate companion would represent 10-20% of the primary’s mass; it is an suggestive coincidence that 2M1207 might have an unusually massive disk and has an unusual planetary-mass companion. However, since the estimated mass of the planet would then still be comparable to the disk it is difficult to imagine that the companion formed like the planets in our own Solar System. The most likely explanation is that the system formed as double brown dwarfs. The system is more widely separated than any field double brown dwarfs, although existing searches were not sensitive to such extreme mass ratios (Gizis et al. 2003). Planet formation may also be occurring in the inner disk where we observe depleted gas.

## 4. Summary

We have obtained the first ultraviolet spectrum of a *bona fide* brown dwarf. We observe CIV and other emission lines which must arise in hot gas, which we identify as due to accretion, and  $H_2$  lines which must arise in much colder gas, which we identify as circumstellar gas. This brown dwarf is very similar to a classical T Tauri star. The emission lines differ significantly from those of late-M field dwarfs, and we therefore rule out origin in a transition region between the chromosphere and corona.

Further studies of this fascinating system are in order. We have presented our observations in this paper, but further modeling is required in order to estimate the accretion mass rate and other properties of the system. We are obtaining Spitzer mid-infrared photometry of 2M1207 in order to characterize the disk. Sub-mm observations are needed to estimate the disk mass.

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## REFERENCES

- Chauvin, G., et al. 2004, *A&A*, 425, L29
- Gizis, J.E., 2002, *ApJ*, 575, 484
- Gizis, J.E., Reid, I.N., Knapp, G.R., Liebert, J., Kirkpatrick, J.D., Koerner, D.W., & Burgasser, A. J. 2003, *AJ*, 125, 3302
- Gizis, J.E., & Bharat, R. 2004, *ApJ*, 608, L113
- Hawley, S.L., Gizis, J.E., & Reid, I.N. 1996, *AJ*, 112, 2799
- Herczeg, G.J., Linsky, J.L., Valenti, J.A., Johns-Krull, C.M., & Wood, B.E. 2002, *ApJ*, 572, 310
- Herczeg, G.J., Wood, B.E., Linsky, J.L., Valenti, J.A., & Johns-Krull, C.M. 2004, *ApJ*, 607, 369
- Jayawardhana, R., Hartmann, L., Fazio, G., Fisher, R.S., Telesco, C.M., Pina, R.K. 1999a, *ApJ*. 520, L41
- Jayawardhana, R., Hartmann, L., Fazio, G., Fisher, R.S., Telesco, C.M., Pina, R.K. 1999b, *ApJ*. 521, L129
- Jayawardhana, R., Ardila, D. R., Stelzer, B., & Haisch, K.E. 2003, *AJ*, 126, 1515
- Kirkpatrick, J.D., Reid, I.N., Liebert, J., Cutri, R.M., Nelson, B., Beichman, C.A., Dahn, C.C., Monet, D.G., Gizis, J.E., & Skrutskie, M.F. 1999, *ApJ*, 519, 802

- Liu, M.C., Najita, J., & Tokunaga, A.T. 2003, ApJ, 585, 372
- Luhman, K.L., et al. 2005, ApJ, 620, L51
- Mohanty, S., Jayawardhana, R., & Barrado y Navascues, D. 2003, ApJ, 593, L109
- Mohanty, S., et al. 2004, ApJ, 609, L33
- Mohanty, S., Jayawardhana, R., & Basri, G. 2005, ApJ, in press (astro-ph/0502155)
- Muzerolle, J., Hillenbrand, L., Calvet, N., Hartmann, L., & Briceno, C. in Young Stars Near Earth: Progress and Prospects, ASP Conference Series Vol. 244. Edited by Ray Jayawardhana and Thomas Greene. San Francisco: Astronomical Society of the Pacific, ISBN: 1-58381-082-X, 2001., p.245
- Perryman, M.A.C., et al. 1997, A&A, 323, L49
- Schneider, G., et al. 2005, AAS Meeting 205, #11.14
- Scholz, R.-D., McCaughrean, M.J., Zinnecker, H., & Lodieu, N. 2005, A&A, 430, L49
- Sterzik, M.F., Pascucci, I., Apai, D., van der Blik, N., & Dullemond, C.P. 2004, A&A, 427, 245
- Valenti, J.A., Johns-Krull, C.M., & Linsky, J.L. 2000, ApJS, 129, 399
- Weinberger, A.J., et al. 2002, ApJ, 566, 409

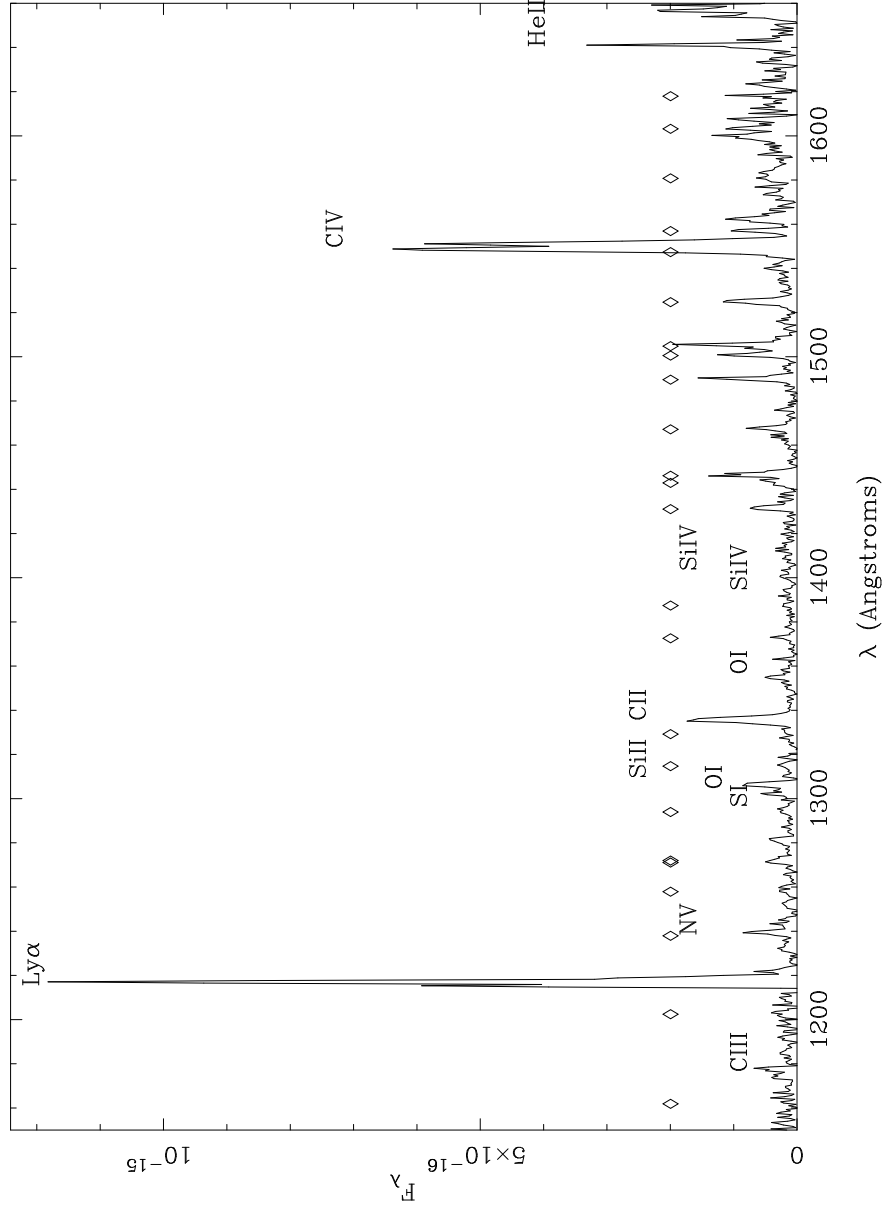


Fig. 1.— HST/STIS spectrum of 2M1207. We detect numerous ions. The positions of SiIV and SiII are marked, but they are not detected. The diamonds mark the positions of the H<sub>2</sub> lines pumped by 1215Å and 1216Å identified in TW Hya by Herczeg et al. (2002). Most are clearly detected, and those absent are significantly weaker in the TW Hya spectrum and thus are expected to be too faint to detect.

Table 1. Emission Line Strengths

| Ion  | $\lambda$ ( $\text{\AA}$ ) | Flux ( $10^{-16}$ erg/sec/cm <sup>2</sup> ) |
|------|----------------------------|---|
| CIII | 1176                       | 1   |
| NV   | 1238                       | 5   |
| SI   | 1296                       | < 1   |
| OI   | 1304                       | 2   |
| CII  | 1335                       | 5   |
| OI   | 1356                       | 1   |
| SiIV | 1394                       | < 1.5                                       |
| SiIV | 1403                       | < 1.5                                       |
| CIV  | 1549                       | 29  |
| HeII | 1640                       | 6   |